

REMOTE SENSING APPLICATIONS IN FORESTRY

THE DEVELOPMENT OF SPECTRO-SIGNATURE
INDICATORS OF ROOT DISEASE ON
LARGE FOREST AREAS

R-09-038-002

By
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U.S. Department of Agriculture

Annual Progress Report

30 September, 1966

A report of research performed under the auspices of the
FORESTRY REMOTE SENSING LABORATORY,
BERKELEY, CALIFORNIA—

A Coordination Facility Administered Jointly By

The Pacific Southwest Forest and Range Experiment Station of the
Forest Service, U.S. Department of Agriculture and by the
School of Forestry, University of California

For

NATURAL RESOURCES PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE
ADMINISTRATION



Frontispiece--Merchantable stand of 50 year old Douglas-fir "rot thrown" by the fungus Poria weirii. Note typical decay pattern in splintered stump at center of picture. Leaning dead tree on left exhibits sluffed bark. Living standing tree on right has thin ragged crown, poor color, and decreased terminal and lateral growth. In addition, root rot weakened trees exhibit increased susceptibility to attack by Douglas-fir bark beetles.

ABSTRACT

N66-39700

Research employing remote sensing techniques in the visible, near infrared, and thermal infrared portions of the electromagnetic spectrum has been attempted with aerial sensors to discriminate differences in the appearance of healthy and Poria weirii root rot infected Douglas-fir trees. A spectrometric analysis of foliage from the tops of 45 sample trees that represent three tree condition classes, three age classes, and three seasons of the year is considered. Special equipment and aerial sampling techniques were designed and developed to implement the collecting of the tree top samples. The use of special aerial photography and thermal infrared radiometer readings is also discussed in this report.

Author

ACKNOWLEDGEMENTS

This research was performed under the sponsorship and financial assistance of the National Aeronautics and Space Administration for the Manned Earth-Orbital Experiment Program in Agriculture/Forestry (Contract Number R-09-038-002).

The cooperation and assistance of various members of the following organizations have facilitated implementation of this remote sensing project during the past year:

Pacific Northwest Regional Office, U. S. Forest Service, Portland, Oregon.

Pacific Southwest Forest and Range Experiment Station, U. S. Forest Service, Berkeley, California.

Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service, Portland, Oregon.

Agricultural Engineering, Agricultural Research Services, Forest Grove, Oregon.

Bonneville Power Administration, U. S. Department of Interior, Vancouver, Washington.

Weyerhaeuser Company, Centralia, Washington.

University of California, Berkeley, California.

Barnes Engineering Company, Stamford, Connecticut.

The time and experience of many of these technical and professional scientists was willingly provided at no cost to NASA in the development of techniques and methods to solve the root rot disease problem that so vitally affects one of our major natural resources. Their contributions to this research study are gratefully acknowledged.

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INTRODUCTION

Multispectral remote sensing techniques offer an excellent opportunity to appraise several forestry problems of economic and physical importance in relation to the supply of our total earth resources. One of the serious forestry problems is the reduction of growth and extensive loss of the timber resource caused by forest diseases. Spectral signature indicators of tree killing diseases may help identify and locate centers of distressed timber that would otherwise be unsalvaged and continue to expand, thereby creating a serious impact on our forest economy. With the advent of new remote sensing techniques and subsequent application to forest disease problems, it is envisioned that forest managers will be able to protect the forest resource more effectively and to maximize the use of distressed timber.

Millions of board feet of valuable timber are destroyed or degraded each year by the insidious and continuing attacks of root rot disease (Timber Resources Review, 1958). Extensive stands of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), a major commercial timber species of the Pacific Northwest, suffer heavy losses because of the root rot disease, Poria weirii (Murr.). (See Frontispiece). Trees are weakened by the disintegration of their root systems, readily "rot thrown," and are highly subject to "wind throw." Root rot centers occur sporadically in remote areas (Figure 1) and generally in insufficient volume and accessibility to warrant economic salvage. If all other

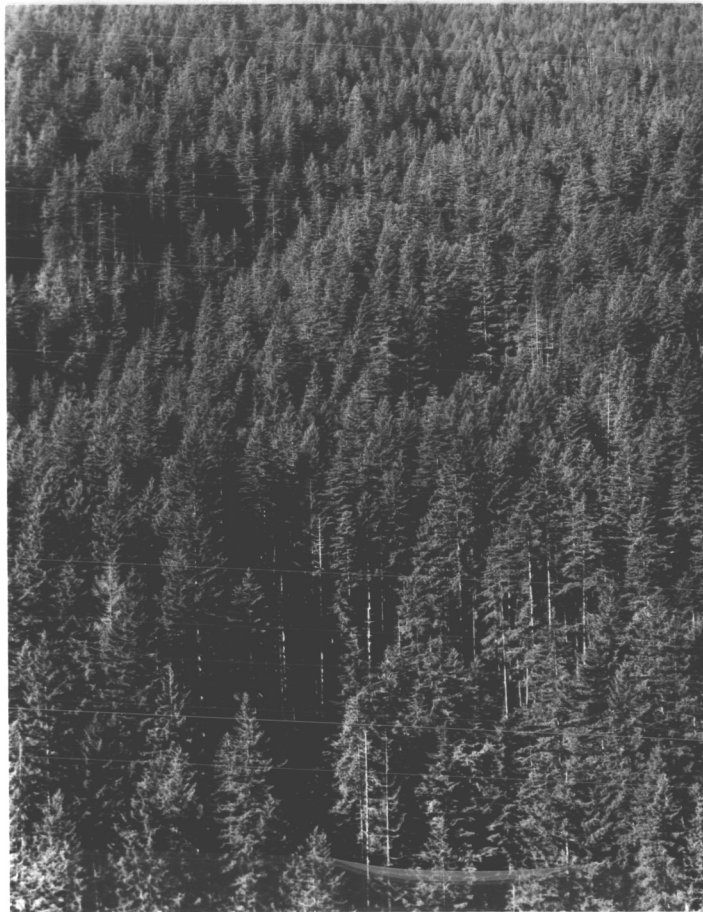


Figure 1.--Oblique photograph showing typical root rot disease distribution pattern indicated by scattered open patches in an 80 year old stand of Douglas-fir in Washington. Centers of infection range in size from a few hundred square feet to an acre or more in extent.

adjacent centers of infection were known, the forest manager could alter plans to economically remove all stages of diseased timber and minimize spread of the disease.

Survey methods to locate and appraise centers of infection over large and frequently inaccessible mountainous terrain are costly and time consuming. Only a small portion of a working circle or small timber holding can be surveyed by field crews in a single season. "Ground truth" techniques currently in use require drilling trees and or digging into root systems to obtain evidence of disease symptoms. The new remote sensing technology has created great interest in the scientific community for the development of more efficient survey methods for locating and evaluating the incidence of root rot disease centers in forested areas.

Initial inspection of several remote sensing techniques indicated that the visible, near infrared, and thermal infrared portions of the electromagnetic spectrum were potentially capable of differentiating root rot infected trees from healthy trees. Special aerial photographic techniques have proved successful in surveying tree damage and tree mortality caused by forest insects. A feasible photographic technique would insure implementation of a practical disease survey method in a relatively short time. Thus, research was directed toward determining whether an optimum film-filter existed that would enable diseased trees to be discriminated from healthy trees. Recent research indicated that a spectro-photometric analysis of diseased and healthy foliage might be effective in limiting the number of photo combinations to be tested. The development of techniques and specialized equipment for collecting and preparing the foliage samples for spectral analysis constituted

Phase I of this study. A second phase of this study consisted of testing of two types of special photography that are effective for forest insect damage evaluations. A third phase of this study was the testing of the usefulness of a nonimaging infrared sensor to discriminate between diseased and healthy Douglas-fir.

LITERATURE REVIEW

The application of remote sensing techniques to root rot disease problems in the forest complex has been attempted once previously but without success. Publications and reports on the biology of Poria weirii root rot were studied to become better acquainted with the disease and the impact on the forest resource. Disease symptoms and methods of identifying the pathogen, distribution pattern and epidemiology, host tree types subject to attack, and ground survey methodology were reviewed and discussed with forest pathologists. Forest pathologists from the Insect and Disease Branch of the Division of Timber Management, Pacific Northwest Region; the Pacific Northwest Forest and Range Experiment Station, U.S.F.S.; and Weyerhaeuser Co. offered suggestions and were helpful in orienting the program and assisting in the implementation of the field work.

In addition, a review was made of recent publications on aerial photo techniques for timber inventories and forest insect damage evaluation surveys for possible refinement of techniques to apply to the root rot survey problem. Current literature on remote sensing techniques was also studied for any significant indications of effective systems that would help solve the Poria weirii survey problems.

JUSTIFICATION

Forest diseases have a greater total adverse effect on forest productivity than all other causative agents. Forty-five percent of the growth loss in forested areas of the United States is attributable to diseases (Timber Resources Review, 1958). In 1952, 300 million board feet of sawtimber was estimated to be killed by root diseases. Losses of this magnitude are of great interest to those concerned with making earth resource surveys and inventories from orbital altitudes.

This research is needed to develop techniques for rapidly detecting the incidence of diseases which cause tremendous world-wide damage to forests. Foresters and land managers must have adequate detection techniques to counter the impact of tree diseases and to maintain healthy forests.

Poria weirii root rot is by far the most destructive disease of Douglas-fir in Washington and Oregon. Douglas-fir is the most important timber species in the Pacific Northwest, representing 57 percent of the total sawtimber volume in that region; hence, a root rot disease survey technique would provide tangible benefits to the forest economy of the United States.

METHODS AND PROCEDURES

This remote sensing techniques research for discerning root rot infected trees from healthy trees deals with three portions of the electromagnetic spectrum; the visible, near infrared, and thermal infrared. Research covered in this progress report consists of three distinct phases; spectrometric analysis, aerial photographic interpretation, and infrared heat sensing. Each phase will be considered separately

with appropriate illustrations.

A. Spectrometric analysis

A spectrometric analysis of Douglas-fir foliage from the tops of healthy and infected trees was considered essential to ascertaining the best film-filter combination for an aerial photo survey of root disease impact over large forest areas. The aerial photographic tone of a particular tree depends primarily on the amount of light reflected to the camera from the top of the tree. This fact, coupled with the necessity for numerous replications of foliage samples to establish statistical confidence levels before accepting any single film-filter combination, emphasized the need for a better and more flexible method for collecting foliage samples from the tops of trees. Included in the spectrometric analysis phase of this study were (1) the development of special aerial sampling techniques and equipment, (2) the selection of operating areas, (3) the use of methods and procedures for collecting 'ground truth' data, and (4) a statistical analysis of the reflectance data obtained from the G.E. spectrophotometer.

1. Aerial sampling techniques and equipment

An analysis of current tree top sampling techniques was made to determine the most rapid and efficient means of securing many branch samples from the tops of dominant trees in forested areas. It was found that in general one or two sampling methods are normally used consisting either of an experienced tree climber cutting the top portion of a tree, or of an expert rifleman shooting at a branch in the tree top. Where small trees and few samples are needed these systems have merit. However, both methods had serious disadvantages for the multiple samplings necessary

for this study.

Standard tree climbing methods are extremely laborious and time consuming. Including travel time between trees, only about four tall trees (130 feet to 230 feet) can be climbed and 'topped out' in a day by an experienced climber. The 'topping out' of eight to twelve feet of a tree for a branchlet sample is destructive to tree form and to future cone production, and precludes the use of the tree top for later sampling. For the tree climber to secure just one or two small branchlets from the top and outer portion of the tree crown is even more difficult, time consuming, and dangerous.

Shooting branchlets out of tree tops with a rifle is difficult, time consuming, and uncertain, especially in tall dense stands. Wind movement in the tree top causes an unsteady target and a severed branchlet may 'hang up' in the upper tree crown. In many instances only about one rifle-severed-branchlet out of ten reaches the ground. In this study branchlets from the tops of 45 trees were needed for spectral analysis and comparison. The time factor and lack of experienced tree climbers or expert marksmen necessitated a different approach.

In previous studies an efficient tree marking technique had been developed which used a helicopter to apply fluorescent paint or weighted streamers to tree tops. The success of this technique suggested that the use of helicopters for tree sampling of dominant trees might also be feasible. A highly skilled helicopter pilot with considerable experience in low level cargo handling or forest spraying operations can safely fly a Hiller 12E or Bell G3B helicopter close to the tree tops. Trees occupying the highest part of the forest canopy must be selected

for sampling from the helicopter. Several extra trees could be selected to replace any that the helicopter pilot might reject because of adverse approach or unusual wind conditions.

A special pole pruner was developed cooperatively by the writer and ARS engineering personnel to secure foliage samples of Douglas-fir tree tops from a hovering helicopter. The pole pruner is able to cut an 8 to 12 inch long branchlet rapidly with a minimum hovering time for the helicopter, and, to hold the cut branchlet until specifically released by the operator (Figure 2). A close up of the scissors type cutting head is shown in Figure 3. A description of the special eight foot pole pruner, cutting head, and CO₂ power operation is presented in a forthcoming U. S. Forest Service Research Note.

2. Operating areas

Forest pathologists from the Pacific Northwest Forest and Range Experiment Station and Weyerhaeuser Co. were contacted to suggest areas in Oregon and Washington that might be suitable for conducting remote sensing techniques research on root rot disease in Douglas-fir. It was determined that a series of 12 ground study plots that had been established previously would provide a good study base with adequate 'ground truth' data. Detailed information about the incidence of Poria weirii had been obtained on this series of 10-acre plots on a regular basis for many years. Thus a reasonably complete history of the incidence of root rot on each plot was available.

Various factors were considered in the final selection of plots to be used in the first year research program. It was decided that plots should be of the same or similar site conditions, have a wide



Figure 2.--This new sampling technique for collecting branchlets from the tops of dominant trees is simple and efficient. The light weight pole pruner is powered by CO₂ clips and retains the sample until released by the operator. Highly skilled helicopter pilots are required for this precise operation.



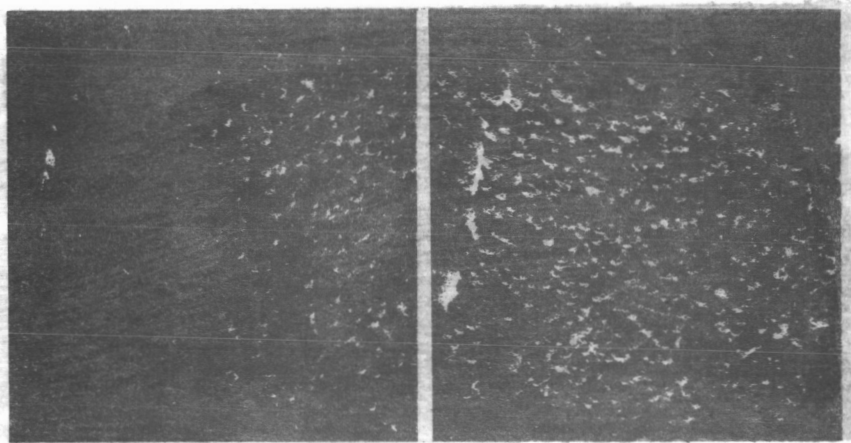
Figure 3 .--Closeup of pole pruner showing scissors type mechanism that cuts and holds branchlet. Note size of branchlet that can be clipped. This clipping system has potential application for collecting scions from "superior trees" and for gathering cones.

range of disease intensity, and not require extensive travel between plots. Three 10-acre plots from the series were selected that had similar site conditions (soil, slope, aspect, moisture, and climatological factors), had a range of disease classes and healthy trees, were within a radius of five miles from one another, and were relatively close to Portland, Oregon, to minimize travel time by ground or air. Each plot was representative of a specific age class, i.e., young growth stand (40 to 80 ft.), second growth stand (90 to 120 ft.), and old growth stand (130 to 225 ft.). (Figures 4 and 5.) The three plots are located near Carson, Washington in the Wind River drainage and are about 60 miles from Portland, Oregon.

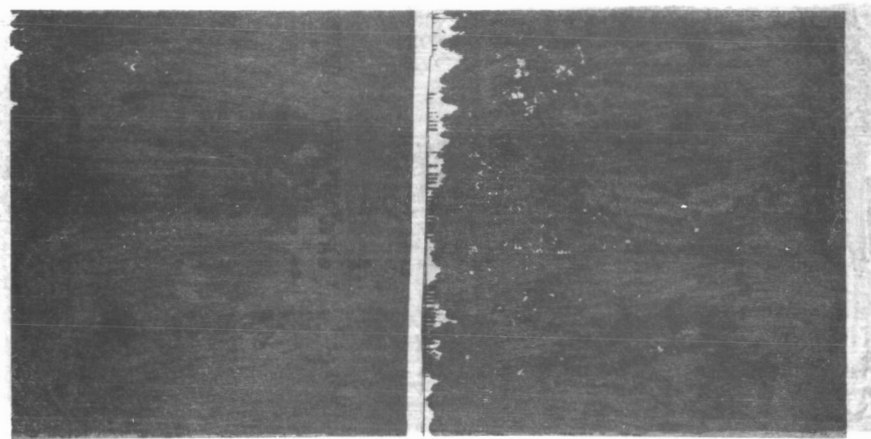
3. Collecting data

Ground and aerial techniques were used to collect the foliage samples for the spectrometric analysis. Fifteen dominant Douglas-fir trees consisting of five trees in each of three tree condition classes were selected on the ground in each plot. The three condition classes were healthy, root rot infected with no visible crown symptoms, and infected with visible crown symptoms. Foliage samples were collected at three separate times about one month apart to determine whether moisture conditions that affect tree growth would also maximize reflectance differences between healthy and infected Douglas-fir trees.

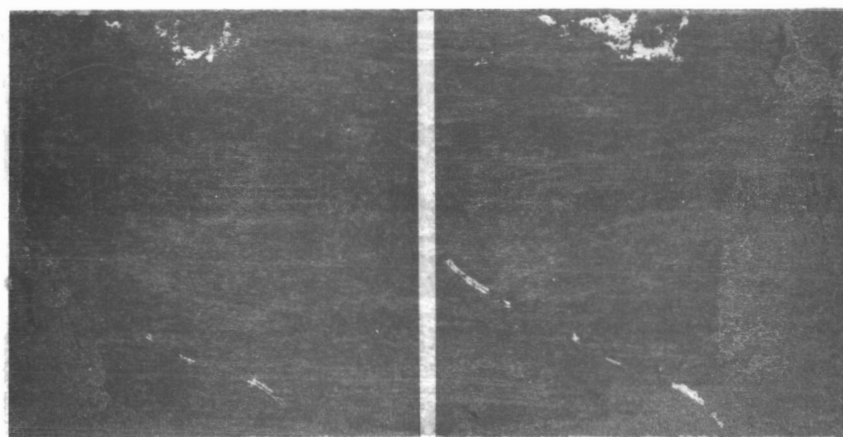
Positive identification of the presence (or absence) of root rot disease was determined by drilling about six inches above ground level into the trunk of the tree with an increment borer (Figure 6). Disease centers were well marked on the 10-acre plot sheets so that considerable time was saved in locating an area in which to select trees of the three condition classes. Two to four increment cores were usually



a. Young growth stand.

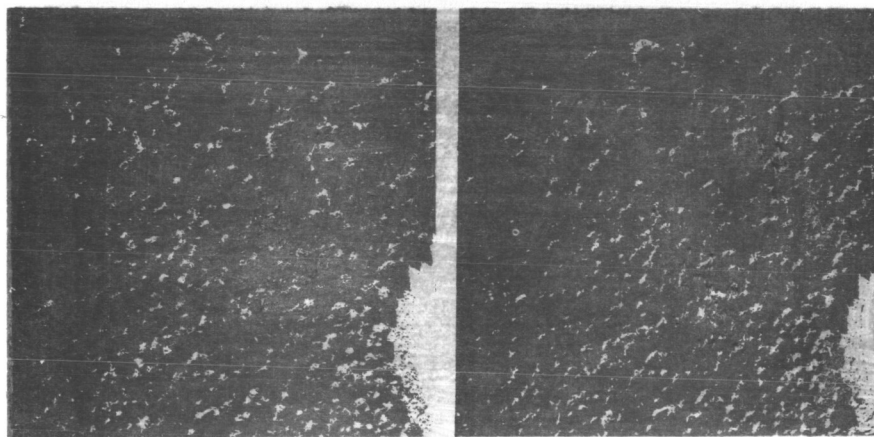


b. Second growth stand.

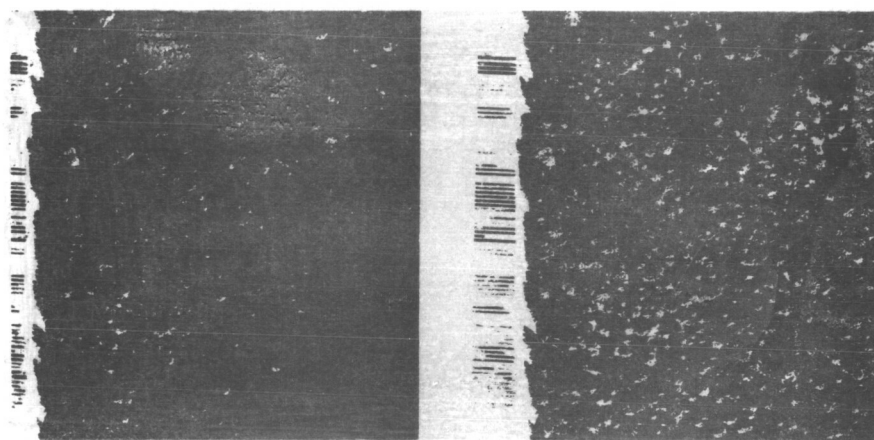


c. Old growth stand.

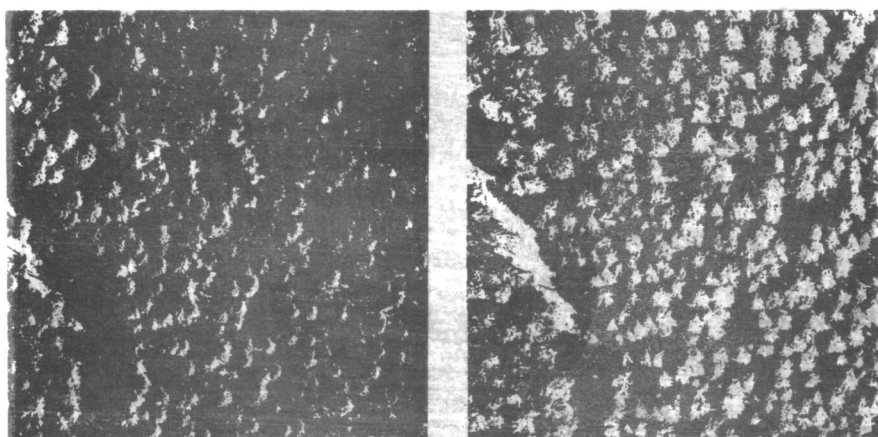
Figure 4.--Ektachrome Aero (E-3) color photographs of *Poria weirii* root rot disease study plots in Douglas-fir at a photo scale of 1/2500. Young growth stands range from 40 to 80 ft. (a.). Second growth stands range from 90 to 120 ft. (b.). Old growth stands range from 130 to 225 ft. Note excessive stereo parallax in large-scale photography on "old growth" stands.



a. Young growth stand.



b. Second growth stand.



c. Old growth stand.

Figure 5.--Ektachrome Aero Infrared photographs of *Poria weirii* root rot disease study plots in Douglas-fir at a photo scale of $1/2500$.



Figure 6.--Pathologist drills into base of Douglas-fir with an increment borer to determine presence or absence of Poria weirii root rot disease. Notice darker portion of core (nearest tree) verifying presence of root rot at the center of tree.

taken of many trees to locate and verify presence or absence of root rot in the 45 required sample trees.

One or two extra trees in each condition class were selected and marked. These trees were to replace those sample trees selected on the ground which were considered too difficult by the helicopter pilot. Each tree selected was marked with a painted number on two sides of the trunk. Each plot was gridded at two-chain intervals with four foot yellow stakes, coded by number and letter, and the position of each sample tree was plotted on the 10-acre plot sheet. Plot sheets were helpful to ground personnel in relocating trees and in expediting travel between trees when actual samplings took place. Annotated plot sheets were also used effectively by the helicopter crew in the aerial operations.

Prior to actual aerial sampling from a helicopter, 60 tree markers were fabricated which were used to identify sample trees at subsequent periods. Each marker consisted of five, 6-foot strips of plastic ribbon attached 10 inches apart to a string, At each end of the 6-foot string a large washer was attached which served as weight for deploying the folded marker and for retaining the marker in the tree top. Three colors of plastic ribbon were used to denote specific tree condition classes; white for healthy trees, orange for trees infected with root rot but showing no external symptoms, and red for trees infected with root rot and showing external symptoms of foliage discoloration, or short needle and branchlet growth, or ragged distressed form.

Portable radios on Forest Service frequency were secured for communications between ground personnel and the helicopter. Crash helmets

with radio earphones and boom mikes were provided the pilot and tree pruner operator and a standard headset for the ground crews. Hard hats for men on the ground were painted either fluorescent red or yellow to facilitate spotting them from the helicopter. After the helicopter was vectored over the field crew by radio it was relatively easy for the helicopter to follow the field crew from tree to tree.

The first aerial sampling was performed on May 11, 1966. This sampling represented the "winter hardening" period in which only last year's needles were in evidence on the trees. At this time of year all foliage of Douglas-fir is dark green. Only two trees selected from the ground were discarded because of a difficult aerial approach for the helicopter. Additional trees had been selected to meet this contingency so that 45 samples were obtained. After a branchlet was clipped from a sample tree, it was retrieved into the helicopter, numbered, and sealed in a plastic bag. Immediately after sampling, a weighted streamer tree marker of the color designated for the particular tree condition class was hurled into the tree top (Figure 7). All tree markers continued to be clearly visible after five months. Total time to identify the sample trees with the assistance of the ground crew, collect the foliage sample from 45 trees, and mark each tree for future reference (including five mile ferry to the two other plots) required three hours and 10 minutes flying time. The last three trees were sampled and marked in 6-1/2 minutes.

The second aerial sampling was performed on June 27, 1966. This sampling period represented the full bloom of succulent spring growth. Branchlet samples contained both the dark green needles from last year's growth and the light green needles from new growth. The sampling technique

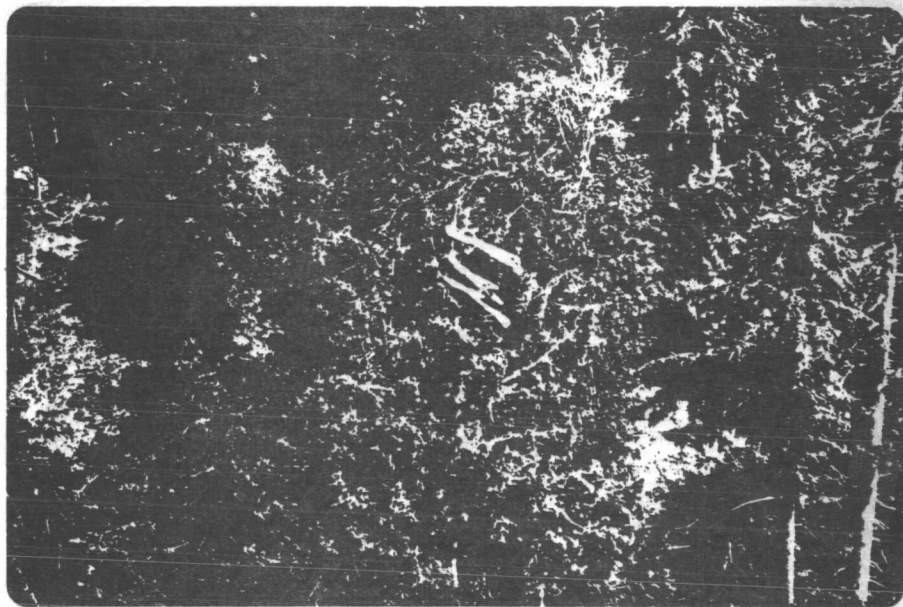


Figure 7.--A color photograph illustrating the appearance of a plastic tree marker as seen from a helicopter. Previous tests of this system of tree marking have shown little or no deterioration of the plastic markers after one year of exposure to the forest environment.

was modified to determine the efficiency of clipping the branchlet and dropping it through an opening in the forest canopy to the field crew on the ground. The helicopter would maneuver over the opening with each sample branchlet and the tree pruner operator would release it to the ground men. Occasionally a branchlet would "hang up" in reproduction or brush and necessitate a second clipping. Unless there are two or three men on the ground however, it is difficult to keep up with the sampling speed of the helicopter team. Retrieving the sample branchlet, labeling it, sealing the plastic bag, and storing the sample securely to prevent accidental loss going through the brush is extremely strenuous for a ground crew of two men. Total helicopter time to collect the 45 samples with this technique on the second sampling was two hours and five minutes.

The third sampling was completed on August 31, 1966. This sampling period represented the "summer hardening" of the new foliage of this year. The color of the new growth was almost as dark green as last year's foliage. Only one ground man was available for this aerial sampling so that all branchlet samples were retrieved into the helicopter. Because the sample trees were still well marked on the second growth plot, it was unnecessary to have a ground man on that particular plot. The young growth stand was easily sampled with minimum help from the ground man. The old growth stand was the hardest to sample and required considerable help from the ground man. Orientation between widely scattered trees was difficult to maintain. Total helicopter time for the third sampling was two hours and ten minutes.

The 45 tree samples in plastic bags were transported in an insulated styrofoam case to the Forest Service laboratory in Portland after each aerial sampling was completed. Foliage from each tree sample was mounted between 1-1/2" x 3" glass plates. Field crews assisted in mounting the tree samples between the glass plates. Completed slides were kept under refrigeration until ready for spectral analysis.

4. Spectrometric analysis and statistical comparisons

The spectral reflectance of the foliage samples was measured in the 0.4 to 1.0 micron band with a General Electric spectrophotometer at Richmond, California in the University of California's Illumination Laboratory. The spectral range of this instrument covers virtually all of the spectrum in which photographic images can be obtained directly on film emulsions. These reflectance data for each sampling period are being statistically compared to determine the most suitable wavelengths in the photographic spectrum wherein the tone contrast differences between diseased and healthy trees may be maximized.

B. Aerial photography

Aerial photographic research in the U. S. Forest Service during the past 15 years has produced several photographic survey methods for estimating mortality and damage intensity caused by forest insects. Many film-filter combinations have been tested and sampling techniques designed to provide forest insect survey information more rapidly and with less cost than ground methods. A manual on photographic survey techniques for estimating forest insect damage in the western United States is now at the printers and close to publication.

Experience with photographic techniques for forest insect surveys indicated that certain film-filter combinations might be effective in evaluating Poria weirii infected trees. Ektachrome Aero (E-3) and Ektachrome Aero infrared photographs were obtained of the three 10-acre plots in late July. The photographs were taken at two scales; 1/5000 and 1/2500. Aerial photography at the time of the three foliage sampling periods was not possible because of adverse weather conditions. Interpretation of the color imagery of the three plots by one interpreter indicates that no significant differences exist between healthy and diseased trees on this particular type of photography. More detailed interpretations remain to be made with the Ekta IR and Ekta Aero in concert to determine whether multiband sensing shows significant discrimination of disease distressed trees. In addition, photography obtained at different times of the year may indicate significant signatures for disease infested trees because of moisture conditions or tree vigor. This important photographic imagery remains to be secured and interpreted.

C. Infrared sensing techniques

Ground observations of root rot infected trees in advanced stages show short needle growth, slight off color from healthy looking trees (possibly due to dessication or physiological change in leaf structure), and a ragged appearance of the entire tree. This decline in vigor of a tree is normally accompanied by an increased stress on the moisture transport system within the tree. The moisture stress hampers the tree's ability to transpire. Consequently, during periods of normal moisture stress, the less vigorous trees are warmer than healthy trees (i.e., they do not transpire as effectively as healthy trees; hence they are not

cooled as much by transpiration.) The trees manifest this temperature difference by radiating in the thermal infrared portion of the electromagnetic spectrum. Thus, it was considered appropriate to explore the 8 to 14 micron band of the spectrum with a sensitive radiometer in an attempt to discriminate temperature differences between root rot infected and healthy trees.

1. Equipment

A Barnes Engineering Company PRT-4 radiometer was secured for an exploratory test. The radiance received by the radiometer head is amplified and transposed electronically into Fahrenheit temperatures. These can be observed on a dial indicator incorporated into the transistorized electronics unit. In order to have a continuous recording of apparent temperature vs. time, a Varian G-11 recorder was borrowed from Bonneville Power Administration and synchronized with the PRT-4. Accuracy of the temperature readings obtained with the PRT-4 radiometer in the 60° to 80° range was approximately $\pm 1^\circ$.

2. Scanning techniques

The PRT-4 radiometer was tested on the 15 sample trees in the "second growth" Douglas-fir plot in early August. Readings were made of each individual tree at approximately 8 a.m., noon, and 5 p.m. The simulated position of the operator using the infrared sensor in the helicopter is shown in Figure 8. The instrument package, including the Barnes radiometer, Varian recorder, and power supply is shown in Figure 9.

Each tree was circled in the helicopter at an altitude of approximately 150 feet above the forest canopy. The PRT-4 radiometer used had a three degree angle of view. Hence, at 150 feet above the tree tops,



Figure 8.--Thermal infrared scanning test was performed from a hovering helicopter as shown. The Barnes Engineering Company PRT-4 radiometer is coupled with a Varian recorder (behind pilot) to provide a continuous record of radiance from the objects present in the three degree angle of view of the radiometer head.

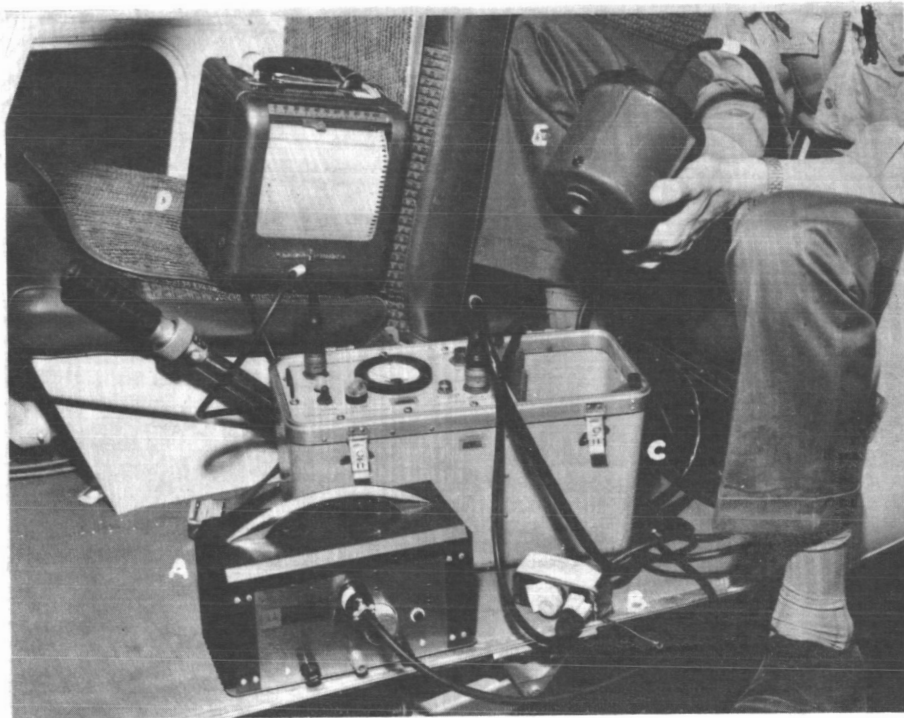


Figure 9.--Equipment used in thermal infrared scanning of Douglas-fir trees for detecting temperature differences between healthy and disease infected trees. Among the instruments used were: (A) Motorola T 101-6A 12 volt DC to 110 volt AC converter; (B) Voltage regulator; (C) Barnes Engineering Co. PRT-4 electronics unit; (D) Verian C-11 recorder; (E) PRT-4 optical head.

the PRT-4 covered a circular area approximately 6 feet in diameter. The radiometer was aimed at the top quarter of each tree (approximately 12 feet in diameter at the mid-point). The helicopter circled close to the tree so that adjacent tree tops were not likely to be included by the radiometer scan unless rough air deflected the sighting. Perfect weather conditions (full sun, and no wind) prevailed at the three sighting periods.

Trees were scanned in a random selection at each sighting period. The scan of each tree was started at one edge of the sunny or shadow side and continued back to the same point on the tree. Between readings the operators hand was held over the opening in the radiometer head to establish a positive cutoff point for separating trees and to provide a record of a fixed temperature base if any fluctuations developed in the radiometer itself. Highest chart speed of the recorder was used (1 inch per minute) to obtain the greatest possible spread of readings for each tree. It required approximately one minute to circle a tree with the helicopter in a semi hovering position.

3. Graph analysis

The continuous temperature readings for a single tree were spaced too close together on the graph to analyze efficiently. 35mm black and white pictures were taken of the individual tree graphs and printed to a common scale of four inches per minute. The 15 second intervals (one inch) could be subdivided into smaller units as desired. An overlay subdivided into five second intervals was considered adequate to determine the average temperature of each tree. Temperature at each point interval was tallied (Figure 10) and the average determined for each tree in the three condition classes.

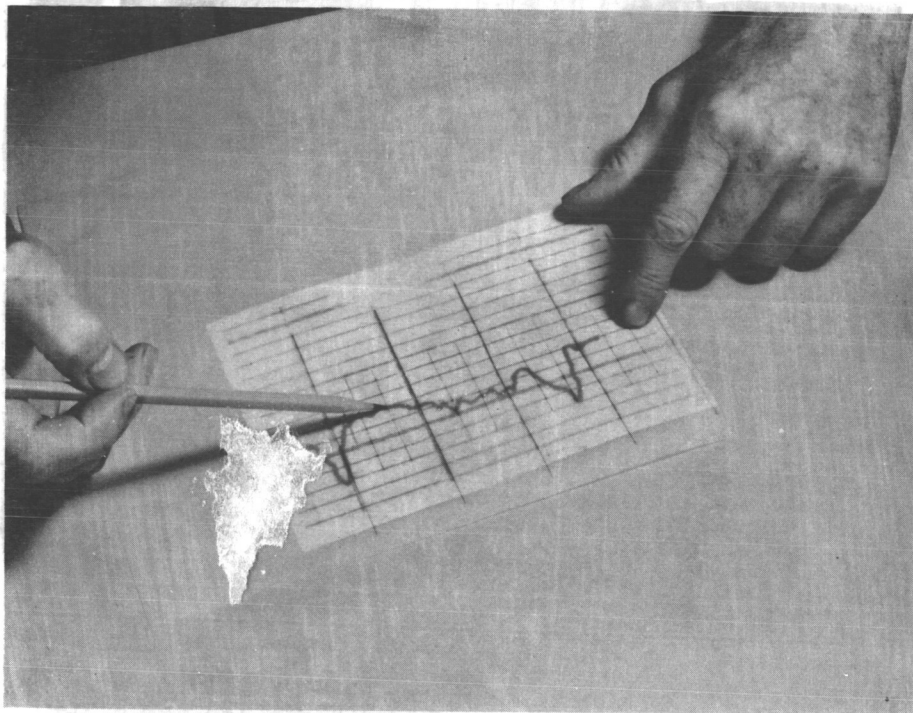


Figure 10.--Apparent temperatures are taken at specific intervals from an enlargement of a graph (Varian strip recorder) to determine the average temperature of a tree scanned with a Barnes PRT-4 thermal radiometer.

DISCUSSION

Progress on the first year's effort to develop spectral signature indicators of Poria weirii root rot infected Douglas-fir trees has been extensive in designing techniques and fabricating special equipment needed to collect spectral reflectance samples.

The following operations have been successfully completed in the spectrometric analysis phase:

1. Forty-five trees representing three stand age classes and three tree condition classes of Douglas-fir were selected in an area of southern Washington where Poria weirii root rot is prevalent. Fifteen representative trees of each age class were drilled with an increment borer for positive identification of presence or absence of root rot disease.
2. Sixty weighted streamer type tree markers were fabricated in three colors for marking selected sample trees from the air.
3. A new type of light-weight pole pruner was designed and constructed for tree top sampling from a hovering helicopter. The pole pruner cuts a branchlet up to one-half inch in diameter and retains it until specifically released.
4. Branchlet samples were clipped from the tops of 45 selected dominant trees from a helicopter at three different periods of time that represent a range of moisture conditions that affect tree growth.
5. Spectral reflectance curves from all sample trees for the three sampling periods were obtained from the G. E. Spectrophotometer at the University of California's Illumination Laboratory.

Remote sensing research in the visible portion of the electromagnetic spectrum involving the use of special types of aerial photography was started this year. Two types of aerial film, Ektachrome Aero (E-3)

and Ektachrome Aero Infrared, were exposed over the three Poria weirii plots at scales of 1/5000 and 1/2500 in an effort to differentiate between root rot disease infected trees and healthy trees. These two films have proved highly effective in differentiating insect killed or damaged trees from healthy trees in many forest conditions of the United States and may provide data applicable to the disease survey problem.

Research in the infrared portion of the electromagnetic spectrum was attempted with a Barnes Engineering Company PRT-4 radiometer which was filtered for the 8 to 14 micron band. Fifteen trees in the "second growth" Douglas-fir plot (containing three tree condition classes) were scanned from a helicopter in the morning, noon, and late afternoon with the Barnes radiometer. The helicopter operated during the day of the test under ideal weather conditions and provided an ideal platform for scanning with the thermal radiometer.

RESULTS

The spectrometric analysis phase of this study has progressed to the stage of statistically analyzing the spectrometric curves derived from the 45 sample trees. The curves have been digitized and the data is being transferred onto punched cards for use with the IBM 7094 computer. Various methods for analysis of the data are being programmed. These include methods to transform the data to make the readings for the five trees in a disease class and site normally distributed, so that an analysis of variance can be applied at given wavelength readings. Another analysis underway will consider the readings for each wavelength as a variable and do a discriminate analysis to find the best wavelengths for discrimination of the curves.

The results of these analyses will be reported in subsequent progress reports of the research.

Preliminary photo interpretation of the Ektachrome Aero E-3 color film indicates that disease infested trees are similar in appearance to healthy trees. Replicated photo interpretations of both films at the two scales will be made and the two color films will be used in concert for possible discrimination of diseased and healthy trees. Results of these interpretations will be included in a subsequent report.

Results of the initial thermal infrared test with the Barnes PRT-4 radiometer are most encouraging. During the 8 a.m. period of scanning, radiance from the Poria weirii root rot infested trees (with and without visible crown symptoms) was found to be significantly different than healthy trees. Table 1 shows the average temperature readings of each tree in the three scanning periods, i.e. 8 a.m., noon, and 5 p.m., and the average temperature of the five sample trees in each condition class.

An analysis of variance was used to test for significant differences between the means of the apparent temperature as follows:

8 a.m.					
	DF	SS	MS	F	
Total	14	67.19			Significant at 1 percent level
Disease Cl.	2	60.28	30.14	57.58	
Error	12	6.91	0.58		
12 noon					
	DF	SS	MS	F	
Total	14	23.49			Not significant at 5 percent level
DC	2	1.90	0.95	0.53	
Error	12	21.59	1.79		
5 p.m.					
	DF	SS	MS	F	
Total	14	22.32			Not significant at 5 percent level
DC	2	1.16	0.58	0.33	
Error	12	21.16	1.76		

Table 1.--Temperatures of healthy and Poria weirii infested
trees scanned by a Barnes PRT-4 radiometer

Trees healthy	Trees with Poria no visible symptoms	Trees with Poria visible symptoms
8 a.m. readings		
67.6	71.1	71.8
68.1	71.2	72.5
68.3	71.4	72.7
68.1	72.4	72.1
<u>67.7</u>	<u>73.8</u>	<u>72.0</u>
average 67.96	71.98	72.22
12 noon readings		
75.2	72.5	76.5
75.8	72.7	75.9
75.8	76.4	74.6
73.9	76.1	74.0
<u>74.8</u>	<u>73.8</u>	<u>74.1</u>
average 75.1	74.3	75.0
5 p.m. readings		
76.2	79.6	76.0
76.8	79.5	75.8
77.6	76.5	77.9
77.8	75.4	77.9
<u>76.6</u>	<u>77.3</u>	<u>78.3</u>
average 77.0	77.66	77.18

The value of F for the 8 a.m. data is 57.58, which is significant at the 1 percent level of confidence. F-values for the 12 noon and 5 p.m. data were .53 and .33 respectively. These values do not indicate a significant difference between the radiance of the trees in the three condition classes at the two time periods tested.

In summary, significant progress has been made this first year in developing multispectral remote sensing techniques for discriminating differences between healthy and root rot diseased Douglas-fir stands in the Pacific Northwest. Spectral reflectance data have been collected from many diseased and healthy trees and are now in the process of statistical analysis. From this analysis spectro-signature indicators may be derived to indicate potential film-filter combinations. The extensive development of aerial techniques and field operations this year has provided a better understanding of some of the disease survey problems. Further developments and refinements will be required before survey techniques can be recommended for operational use.

Initial investigations of aerial photographic imagery with two special color films have been tested. Further investigations, during different seasons of the year, are needed to take advantage of differences in spectral reflectance due to changes in tree moisture and vigor conditions. These environmental factors may affect the discrimination of Poria weirii infected trees from healthy trees over large forest areas. Other promising film-filter combinations will be included in subsequent aerial photographic flights as indicated from the analysis of this year's spectral reflectance data. The most promising results up to the time of

this reporting have been obtained in the thermal infrared portion of the electromagnetic spectrum. A preliminary test with a thermal radiometer provided highly significant temperature differences between healthy and disease infested trees at one period of the day (approximately 8 a.m.). This encouraging result indicates the need for further tests under varying conditions and seasons of the year. A Barnes Engineering PRT-5 thermal radiometer and an Esterline-Angus recorder have been purchased to investigate this remote sensing technique further.

Based on the encouraging results obtained from this study during the first year, and the promise of making still further advances through use of newly developed remote sensing equipment and techniques, it is recommended that additional research in this area be performed during the coming year.

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APPENDIX

The following is a list of U. S. Department of Agriculture personnel who have made contributions to this research study and represent a major salary contribution to it:

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